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Modal Analysis of Power Electronics Module of Spacecraft and its Health Monitoring - An Approach

Jiwan Kumar Pandit^a, D. Roy Mahapatra^b, R. Pandiyan^{a*}^a*ISRO Satellite Centre, Bangalore, 560017, India*^b*Indian Institute of Science, Bangalore, 560012, India*

Abstract

The spacecraft launch environment is quite harsh which can damage the spacecraft electronics. The high intensity vibrations occurring during this phase are transmitted to the spacecraft structures and its electronic equipment. The high intensity vibrations can be sensed using flexible nano sensors and these inputs could be used by actuators to safeguard the spacecraft electronics.

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1. Introduction

The loads acting on a spacecraft, during its entire life-span, can be broadly categorised as Loads acting during Ground operations, Launch loads and On-orbit loads.

The Ground operation loads consist of:-

- Ground handling
- Transportation (horizontal or vertical by road, rail or air)

* Corresponding author. Tel.: +91 80-25082720; fax: +91 80-25082510.

E-mail address: jkpandit@isac.gov.in

The Launch loads, though act for a lesser duration, but are quite critical for the electronics. These loads occur due to the following events:-

- Lift-off,
- Transonic Maximum Q,
- Engine Cut-off,
- Stage Separation,
- SRB End of flight,
- Spacecraft separation.

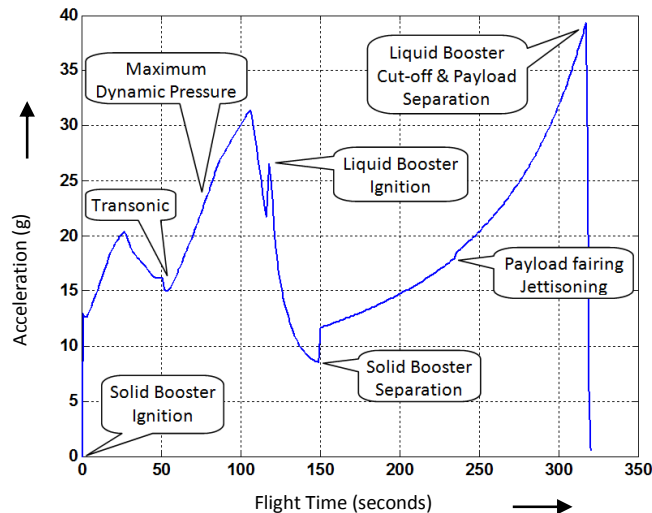


Fig. 1 – Steady state acceleration profile of a typical launch

The on-orbit loads can be caused due to different events as:-

- Pyro-shock for the deployment of appendages (like Solar Panel, or Hold Down and Release Mechanisms),
- Firing of Reaction Control elements (like Thruster, Liquid Apogee Motor etc.),
- Operation of Momentum/ Reaction Wheel
- Impact caused due to meteoroids,
- Thermal loads, etc.

The electronic packages on the spacecraft are adequately designed to withstand the launch loads and are screened out during the qualification level tests. In spite of the due care taken, majority of the failures have been observed during this phase, following a bath-tub curve pattern. This paper mainly focuses on the failure of the electronic packages during launch phase and techniques to mitigate the same with using health monitoring techniques.

2. Finite Element Analysis

The printed circuit board (PCB) of a typical power package having the size as 260X220X2.1 mm³ has been considered in this study. The PCB material is FR4 and its mechanical properties have been experimentally derived. Eight number of spacers made up of AL6061 has been used as stand-offs so as to support the PCB in its enclosure.

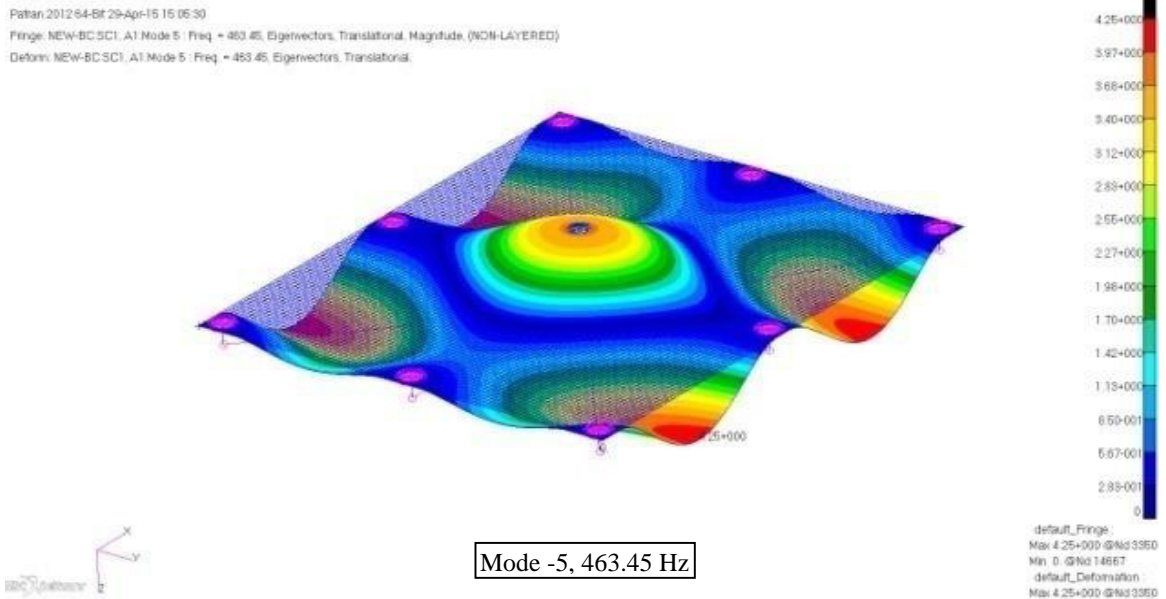
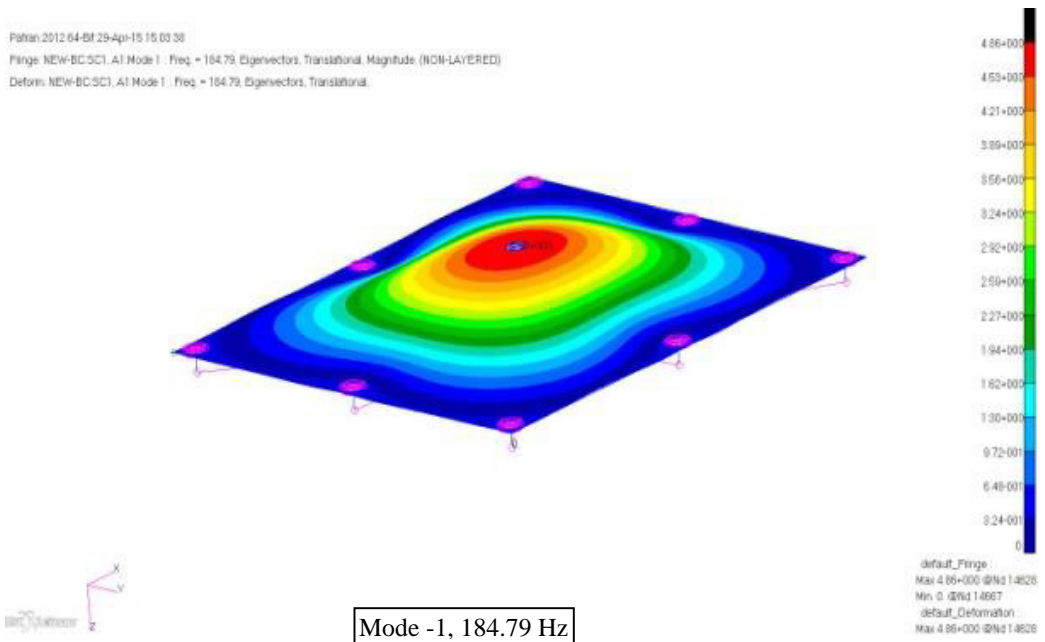


Fig. 2 – Mode shapes obtained by Modal Analysis

The modal analysis has been carried out to find the natural frequencies and the respective mode shapes using PATRAN / NASTRAN software. The first fundamental frequency was obtained at 184.79 Hz (Mode – 1, Transverse mode). The next transverse mode was observed at 463.45 Hz (Mode – 5).

3. Experimentation

The PCB has been identified for FE analysis has been taken for the vibration test. The material properties (FR4) of the PCB have been obtained by 3-point bend test as detailed hereunder:

E (Young's Modulus) = 16.26 GPa, μ (Poisson's ratio) = 0.14, ρ (Density) = 1920 kg/m³

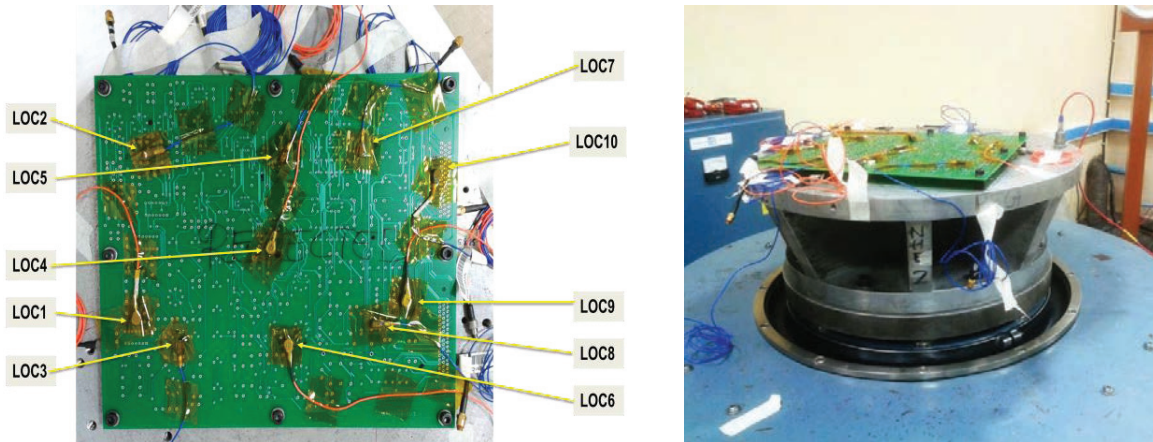


Fig. 3 – Accelerometer mounting on PCB Fig. 4 – PCB on 2-Ton Shaker

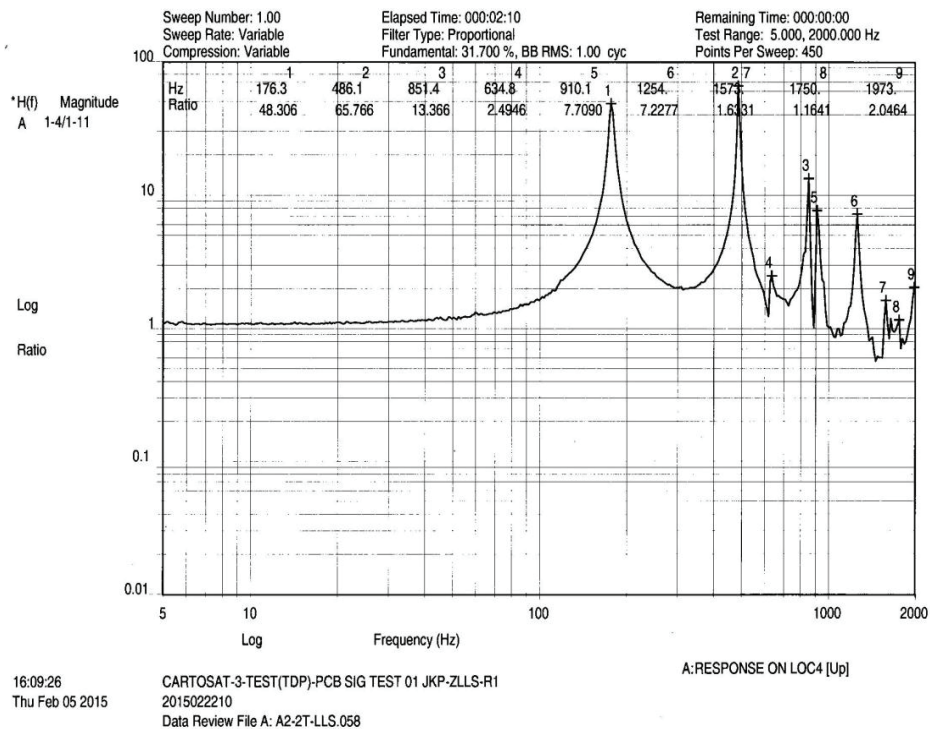


Fig. 5 – Test plot of the vibration test (at LOC-4)

The accelerometers had been mounted at 10 locations as shown in Figure-3. The whole set-up was mounted on 2 Ton Shaker as shown in Figure-4. The sine sweep (from 5Hz to 2000Hz) was carried out with an acceleration input of 0.5g. The response at different accelerometer location has been observed and plotted as in Figure 5.

The experimental results are observed to be closely matching with the FE results as shown in Table – 1.

Table – 1 Comparison between Experimental and FE results

S. No.	Case-1 (at Location 4 of the A/m on the PCB)			
	Mode No.	Experimental (in Hz)	FE Simulation (in Hz)	Remarks
1	Mode-1	176.3	184.79	Transverse mode
2	Mode-2	486.1	463.45	Transverse mode
3	Mode-3	634.8	622.89	Transverse mode
4	Mode-4	851.4	815.3	Transverse mode
5	Mode-5	910.1	910.1	Transverse mode
6	Mode-6	1254.1	1234.5	Transverse mode
7	Mode-7	1573	1578	Transverse mode
8	Mode-8	1750	1886.8	Transverse mode

4. Health Monitoring Approach of PCB

The use of nano sensors in sensing the package vibration pattern will facilitate the necessary input for devising the remedial steps for onboard monitoring of power electronics package. The transverse displacement coming on the module will be sensed by the Structural Health Monitoring (SHM) system. The data obtained through the experiments will provide inputs to be accounted for onboard health monitoring of power electronics package.

The local component fault, on the PCB in an electronic package, can be sensed using sensors, preferably flexible CNT sensors [3], and corrective measures taken there itself using actuators such that there will be reduced adverse impact on the system performance. The schematic approach is shown in Figure 6, wherein a flexible CNT sensor is applied at the critical location in a closed-loop system.

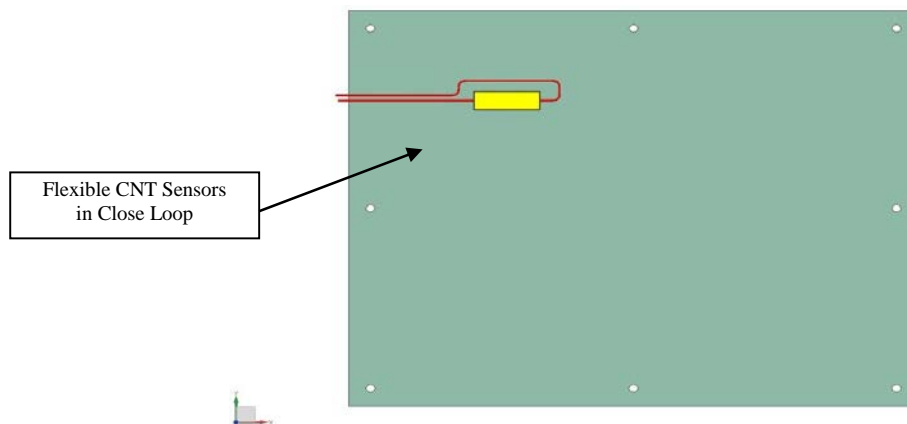


Fig. 6 – Health monitoring approach of PCB using flexible nano sensors

5. Results and Discussion

The fundamental frequencies obtained by the modal analysis carried out using NASTRAN/PATARN software are closely matching with the experimental results. Based on the FE results critical locations on PCB can be identified. The application of the nano sensors in closed-loop SHM system at those critical locations will control the vibration characteristics of the critical electronic components on the PCB and safeguard the electronic package, resulting in a reliable spacecraft mission.

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